Abstract: A TPV GaSb ce]] was tested as part of an effort. to establ]sh a standard method of characterizing such cells. Cell current/voltage (IV) curves were measured at different cell temperatures using black body radiation at various emission temperatures and intensities. The resul]ts of the effects on performance are bri efly aria]. yzed and i ncl ude temperature coefficients, vol tage/i ntensi ty coeff i ci ent, and response to spectral shi ft. .

TPV cell IV curve testing with varying black body emission temperatures, intensities, and cell temperatures

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In this letter, we present, results from the first deliberate program for full characterization of thermophotovoltaic (TPV) cells. A laboratory black body emitter was used as a source for IV curve testing of TPV cells. The following parameters were measured: repeatability, temperature coefficients, intensity effects, and effect of spectral shifts.

TPV cells are similar to ordinary photovoltaic (PV, cells except, that they are fabricated to have a bandgap which corresponds to the peak emission spectrum of a thermal emitter. With a high emissivity emitter and a bandgap matched TPV cell , the efficiency of a TPV system can be higher than that for conventional PV.[1,2]

Although the concept of TPV has been around for some time, no one has yet defined a standardized method for characterizing TPV cells. Detailed knowledge of the emission spectrum and its variations is lacking in previous TPV Lest programs found in the literature. Our solution was to test TPV cells with a black body emitter. Black body emitted radiation follows the spectra] distribution curve defined by Planck's equation. A black body emitter can be set at different operating temperatures to vary the emission spectrum and is readily available for reproducible testing elsewhere. These capabilities are required for accurate prediction and reproduction of performance at different TPV system operating temperatures.

TPV cell series resistance losses are current dependent, therefore output current and power are nonlinear with intensity. This requires that intensity be varied for each black body emission spectrum. The open circuit voltage is dependent on the logarithm of the intensity, requiring intensity corrections to the cell voltage. Since cell voltage is primarily "temperature dependent, cell IV data must also be taken at different cell temperatures.

In summary, obtaining IV curves while varying black body emission temperature, intensity, and cell temperature produces many of the cell parameters required for complete TPV cell modelling.

A GaSb cell supplied by JX Crystals was used for our test series.[a] The cell. was exposed to black body emissions at temperatures of 1200°C and 900°C. Intensity was varied by placing the cell 0.5", 1.5", and 2.5" from the black body source. These distances produced intensities of 1.28, 0.303, and 0.141 W/cm^2, or 4.8%, 1.1%, and 0.53% respectively of full black body intensity at, 1200°C. Intensities were measured with a radiometer and calculated using an optical model furnished by the black body manufacturer. Only the first. distance, 0.5", was selected for

[a] Please note that this cell was not. necessarily a representative sample of JX Crystals's products.

testing at 900°C - the intensity was 0.458 W/cm^2, or 4.4% of full intensity.

To vary cell temperature, the temperature of a circulating water bath was varied from 8°C to 40°C. Its temperature was accurate to within 1°C as measured with a thermometer and a thermocouple. For intensities of 1.28, 0.458, 0.303 ,and 0.141 W/cm^2, the cell temperature was measured and calculated to be 2°C, (). '/"C, 0.5°C, and 0.2°C respectively, higher than the water bath temperature.

When the same test was performed consecutively, the IV curve repeatability was within +/-1%. When the same tests were performed on a different, day, repeatability was within +/-2%.

The overall 2% repeatability was better than the accuracy of the testing system. The black body temperature has an accuracy of 10°C, which corresponds to an intensity error of 2.8%. The radiometer intensity readings have a maximum possible error of 15%. The IV data logger is calibrated to an accuracy of 0.5%. The repeatability of the tests demonstrates that this TPV testing procedure is potentially a valid standardized test method. Since the repeatability was good, some additional data analysis was performed.

First, an analysis was performed on the effects of cell temperature on the most easily measured cell parameter, Voc. Voc temperature coefficients were obtained by taking the slope of the first order regression line of Voc versus cell temperature at three intensities and two black body temperatures. One data point at 8°C and 0.5" distance for the 1200°C black body was dropped due to poor fit. The average of the Voc temperature coefficients was -0.001205 V/°C with a range of -0. 0011.4 to -0.00327 V/°C. 1 t is obvi ous from Fi gure 1 that Voc is dependent upon intensity as well as temperature. Each data point represents the average of at least three test runs.

A plot of Isc versus water bath temperature is shown in Figure 2. Unlike the Voc temperature coefficient, the Isc temperature coefficient has an in tensity dependence. To normal ize the Isc coefficients for all intensities, they were scaled by dividing by the corresponding Isc output for that intensity. Using this approach, the average for the 1200°C black body values is 0.31 %/°C with a range of 0.24% to 0.37%. Since the Isc temperature coefficient was not well behaved, the maximum power data was not analyzed.

'J'he dependence of Voc on intensity was determined next. Theory shows that Voc has a logarithmic dependency on intensity.[3] For a 1200°C black body emission temperature, this relation was found to be: Voc = .129 * $\log_{10}$(intensity W/cm^2) + (temperature constant) . The temperature constants are .366, .352, and .341 Volts for 10°C, 20°C, and 30°C cell temperatures respectively, as shown in Figure 3. Since the Voc temperature coefficient was known, it was used to correct the Voc at, water bath temperatures to actual Voc at corresponding cell- temperatures, for data points in Figure 3.

The power output was analyzed next. The respective maximum power outputs at the three distances, 0.5" , 1 .5" , 2 .5" , were 9.33, 1.978, 0.731 mW for the 1200°C black body, at 10°C cell temperature. While the intensity at 0.5", is 4.2 and 9.1 times greater than that at 1.5" and 2.5" respectively, the calculated maximum power is 4.7 and 12.8 times greater. This is shows an apparent efficiency increase as intensity is increased.

Testing at different black body temperatures demonstrates the effect of spectral shift on performance. When comparing a 1200°C black body to a 900°C black body, the intensity of the emission is reduced by a factor of (T_2^4/T_1^4), using absolute temperatures. The 900°C black body emission intensity should be 40.2% of that at 1200°C. However, the measured test cell Isc at 900°C was only 19.7% of the Isc at 1200°C. This agrees with the expected effect of a spectral shift on the performance of the test cell. The bandgap of the GaSb test cell is .69 eV (1730 nm), when its temperature is about 20°C. The peak wavelengths for black body emission at 1200°C and 900°C are 1.970 nm and 2470 nm respectively. Although they are both lower in energy than the bandgap of the cell, the 1200°C black body emission is a better match to the spectral response of the test cell.

Actual quantitative results of performance for different emission spectra cannot be easily predicted simply from the performance at a few spectra. More exact predictions are possible with spectral. response tests of the cell. Spectral response tests at different cell. temperatures are planned to be completed at. a later date and may be reported at that time.

In conclusion, the research proves that the described TPV cell. testing procedure is repeatable and an identical or similar procedure is necessary for complete TPV cell characterization.

For complete TPV cell characterization, spectral response testing, light reverse IV curves, dark forward and reverse IV curves, and possibly radiation ef’feet-s testing would be necessary to supplement the described TPV IV testing.

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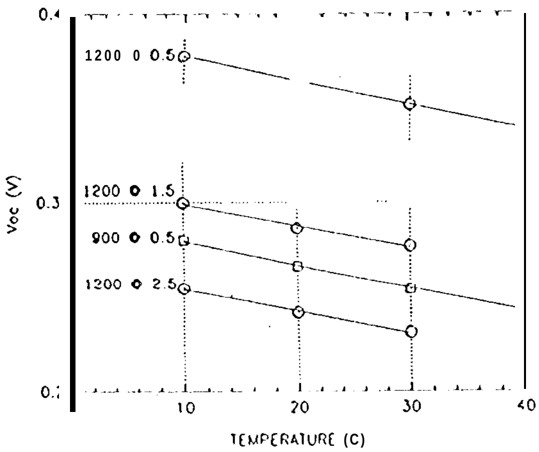
FIG. 1.

Linear dependency of Voc on cell temperature for various emission intensities and temperature.

Voc temp. coefficient =- -1.2 m~~W~~V/°C

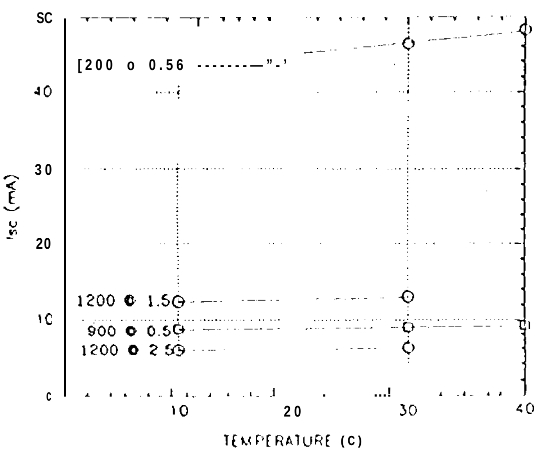


0.4
0.3
0.2
Voc (V)
1200 0 0.5
1200 O 1.5
900 O 0.5
1200 O 2.5
10
20
30
40
TEMPERATURE (C)

FIG. 2.

Linear dependency of Isc on cell temperature for various emission intensities and temperature.

Isc temp. coefficient ≈ 0.31 %/°C



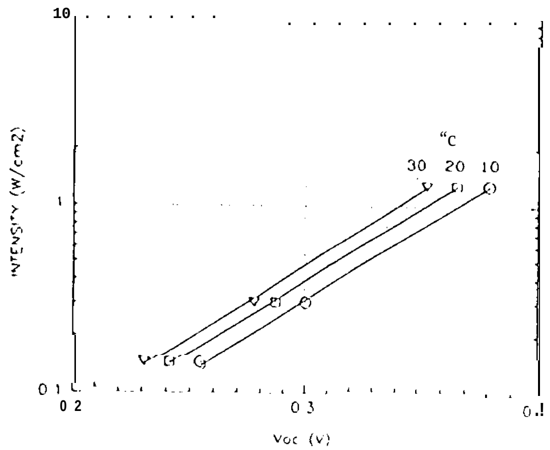
1200 o 0.56
1200 o 1.5
900 o 0.5
1200 o 2.5
Isc (mA)
TEMPERATURE (C)

FIG. 3.

Logarithmic dependency of Voc on emission intensity at various cell. temperatures.

Voc = . 1.29 log (intensity W/cm^2) + temp. constant.

Temp. constants = .366, .352, .341. V for 10°, 20°, 30°C cell temperature.



10
1
0 1
0 2
0 3
Voc (v)
°C
30
20
10